AMERICAN MUSEUM NOVITATES

Number 687 | Published by THE AMERICAN MUSEUM OF NATURAL HISTORY New York City | Jan. 11, 1934

55.2,22 (82.9)

THE "ARGILES FISSILAIRES," A SERIES OF OPAL-BEARING ROCKS OF PATAGONIA[1]

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In an earlier paper[2] by the writer, a detailed description of the petrology of the mammal-bearing rocks of Patagonia was given. These rocks were found to be, in the main, bentonites, bentonitic ashes and volcanic ashes. During the course of this study the need for further study of more of the closely related rocks became apparent. The rocks described in the present paper have been referred to as the "Argiles fissilaires" and generally underlie the main mammal-bearing Casamayor Formation.

The writer wishes to thank Professor P. F. Kerr of Columbia University for his coöperation in making and interpreting the X-ray analyses of the rocks described in this paper.

[3]Ameghino gave the name "Argiles fissilaires" to non-fossiliferous rocks underlying the *Notostylops* Beds south of Punta Casamayor. He intended by this name to designate a type of rock, rather than a particular formation, yet he generally applied it only to rocks at about this horizon, and it has come to be used in the literature almost like a formation name.

It is of great importance in an interpretation of the stratigraphic relations to know whether the "Argiles fissilaires" are distinct from the *Notostylops* Beds or Casamayor Formation or whether they represent a part of a more or less continuous series and should be included as a part of the Casamayor.

The "Argiles fissilaires" rocks are lithologically quite different from the soft bentonitic rocks which form the main part of the *Notostylops* Beds, for they are hard, flint-like rocks which form prominent ledges due to the tendency for them to resist erosion to a greater degree than do the bentonitic rocks. If the "Argiles fissilaires" rocks are different not only lithologically but also genetically from the typical Casamayor, then it would be in order to regard them as comprising a distinct formation.

[1]Publications of the Scarritt Expedition, No. 20.

[2]McCartney, G. C. 1933. 'The bentonites and closely related rocks of Patagonia.' Amer. Mus. Novitates, No. 630.

[3]Ameghino, F. 1906. 'Les formations sédimentaires du Crétacé supérieur et du Tertiaire de Patagonie.' An. Mus. Nac. Buenos Aires, XV [(3) VIII], pp. 1–568. [Argiles fissilaires, especially p. 103.]

Detailed petrographic study together with X-ray and chemical analyses reveals the fact that the "Argiles fissilaires" rocks have a very close genetic relationship to the Casamayor Formation and that the reason for the difference in lithologic character of the two rock types is that the so-called "Argiles fissilaires" represent zones or beds along which there have moved silica-bearing solutions and these solutions have brought about replacement of the rock itself by an opaline material. The result of the replacement by opaline material is a rock which is very thoroughly cemented, very hard and highly resistant to weathering forces.

The characteristic "Argiles fissilaires" rock of Ameghino from what may be considered the type locality, below the type Casamayor at the mouth of Cañadón Lobo (Cañadón Tournouër of Ameghino), is described in detail in the following paragraphs—No. 148. Beds almost identical in character and position occur along the escarpment bounding the Cuenca de Sarmiento on the south, and at various points inland in northern Santa Cruz territory.

No. 148

Field Observations.—[This and other statements recorded in this paper which have to do with observations in the field are taken from the field notebook of Dr. G. G. Simpson, the leader of the Scarritt Patagonian Expedition.]

The rocks are very distinctive, being composed of very hard flinty material in beds from one to several feet in thickness alternating with softer rocks (bentonites) and usually more brightly colored than the overlying rocks (the so-called *Notostylops* Beds). The hard beds may, as in this instance, be gray when unweathered, but they are often, especially when weathered, colored or mottled bright yellow, orange or red. The presence of innumerable small limonitic nodules in places is also characteristic.

The most outstanding feature displayed by specimens of these "Argiles fissilaires" rocks is their great hardness. The rocks are very fine in grain size, homogeneous in texture, and break with a conchoidal fracture.

Petrographic Study.—Thin section shows the rock to be composed of a mosaic of very small fragments. The fragments are fairly uniform in size and tend to be rectangular or square in shape; they exhibit the properties of volcanic glass and at first one is led to believe they are composed of volcanic glass. It has been found that these fragments

represent original fragments or shards of volcanic glass which have been replaced by silica. The silica is present in the form of opal. The matrix of the fragments is colored a dirty green and evidently represents an impure opaline material. There is a small quantity of micaceous material through the rock. In addition the rock contains many very small fragments of quartz and a few of chalcedony. Fig. 1A is a photomicrograph of the rock. The abundance of fragments or shards is readily seen; rectangular, square, and wedge-shaped pieces are most common. The matrix of the fragments is an impure opaline material.

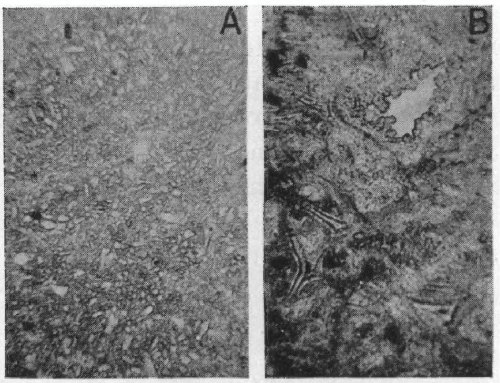

Fig. 1.—Thin sections of the "Argiles fissilaires." A, Typical of the rock, from Cañadón Lobo, specimen No. 148. B, Typical of the rock, from Cañadón Hondo, specimen No. 75. Ordinary light. Magnified about eighty diameters.

Since the rock represents the "Argiles fissilaires" from the type locality it was considered to be of sufficient importance to warrant a very detailed study. In order to make the study conclusive both a chemical and an X-ray analysis were made.

The following table gives the results of a complete chemical analysis of the rock. The analysis was made by F. A. Gonyer of Harvard University:

SiO_2	86.92	K_2O	.20
TiO_2	.31	H_2O-	1.52
Al_2O_3	4.84	H_2O+	4.39
Fe_2O_3	.82	CO_2	none
FeO	.15	P_2O_5	none
MnO	none	SO_3	none
MgO	.04	BaO	none
CaO	.12	ZrO_2	none
Na_2O	.57		99.88

The chemical analysis shows the rock to be remarkably high in silica. Next to silica, alumina is the most abundant constituent but even this constituent is not present in sufficient quantity to be of any importance. There is not sufficient base present to make one of the clay minerals and probably not a definite mica. The analysis indicates rather clearly that the rock is composed essentially of opal, plus small amounts of impurity. The lack of any appreciable quantity of sodium indicates that the original volcanic glass fragments have been completely replaced by other material, in this instance by silica in the form of opal.

The diffraction pattern obtained from an X-ray analysis of the rock reveals the fact that it is not a pure opal rock. Pure opal does not give a diffraction pattern; this material, however, does yield a few lines. The presence of a few lines in the pattern suggests very strongly that the material making up the rock is a mixture of materials such as chalcedony, quartz, micaceous material and iron oxide.

Another interesting rock which is considered to form a part of the "Argiles fissilaires" is found in the vicinity of Cañadón Hondo. It is, as in the case of No. 148, a very hard rock which breaks with a conchoidal fracture. This rock differs from No. 148, however, in that it is green in color instead of light gray.

Nos. 74 and 75

FIELD OBSERVATIONS.—These rocks represent the harder strata of a series which closely resembles the recognized "Argiles fissilaires" in its topographic expression and most of its physical characters, but differs in color. Both the hard beds and the bentonites are green or blue-green, generally rather pale, whereas the typical "Argiles fissilaires" are generally gray or yellowish when unweathered. Furthermore, fossil mammals, apparently of Casamayor age, were found in this series, whereas none have ever been found in the typical "Argiles fissilaires." Laboratory confirmation of the field impression that these are really essentially similar to the recognized "Argiles fissilaires" is therefore of great importance.

PETROGRAPHIC STUDY.—In this instance the rock has a very pronounced development of shard structure. The shards are often long stem-like forms which sometimes branch to give Y-shaped or three-pronged individuals. The shards in this rock differ very greatly in shape from those in the No. 148 rock. The Y-shaped shards in this rock look very like sponge spicules and could easily be mistaken for spicules. There is sufficient difference between the shape of the shards in the two

rocks to suggest that they may represent separate ash falls, which is in any case highly probable from the field data. The groundmass of the rock is composed essentially of a dirty green-colored impure opaline material. This rock differs from the first "Argiles fissilaires" rock described, in that there is a much greater development of chalcedony in the present instance. The rock was originally fairly porous but the pores have since been filled by chalcedony. Many of the shards, too, have been filled with chalcedony. In the cavities and in many of the shards, the central part is filled with chalcedony and the outer part is composed of opaline material. In such instances the opaline material forms a globular-shaped border zone around the chalcedony. This structure is often very pronounced and is made evident due to the refractive index of the impure opal being considerably greater than that of the chalcedony.

Fig. 1B is a photomicrograph of rock No. 75. A number of the spicule-like shards are visible in the picture. The contrast in the shape of the shards in the No. 148 and the No. 75 rocks is well illustrated in Figs. 1A and 1B. Fig. 1B also illustrates a chalcedony-filled cavity with its globular-shaped border zone of impure opal.

Of minor importance as constituents of the Nos. 74 and 75 rocks there are a very few fragments of quartz and plagioclase. There is a rather extensive development of micaceous material, which is at least in part montmorillonite and some of which shows the structure of the parent volcanic glass.

X-ray analyses of Nos. 74 and 75 give patterns very similar to that of No. 148. No. 75 gives a pattern which suggests a mixture of a number of different materials, e.g., chalcedony, quartz, montmorillonite, other micaceous minerals, etc., in fact the pattern of No. 75 suggests a greater mixture of materials than do any of the other "Argiles fissilaires" rocks. However, the pattern of Nos. 74 and 75 is so nearly like that of No. 148 that it is in order to say that these rocks, too, are composed essentially of opal plus some impurity.

In order to establish definitely the genetic relationship between rocks considered to be "Argiles fissilaires" and the bentonitic rocks as in the Casamayor, for example, a study was made of specimens taken from an outcrop in which the two rock types are intimately associated. Specimens numbered 1–5 are taken from the "Argiles fissilaires" exposed in a cliff south of Lago Colhué Huapí.

Nos. 1 to 5

FIELD OBSERVATIONS.—In this locality the "Argiles fissilaires" are closely similar to those of Cañadón Lobo both in appearance and in stratigraphic position. They form a series of horizontally banded but lenticular beds about 115 or 120 feet thick beneath the mammal-bearing ashes and bentonites of the characteristic Casamayor Formation. The beds of the "Argiles fissilaires" series are highly heterogeneous, consisting of alternating hard ashy or opaline beds and softer clay-like bentonites. They are often very brilliantly, but for the most part superficially, colored, the hard beds, especially, being mottled red, yellow, and orange. The contact with the overlying softer, more homogeneous, and paler mammal-bearing beds is gradational, the clay-like strata becoming thinner toward the top and the hard layers thinner and less frequent. Rocks Nos. 1–4 represent the range of variation of the general "Argiles fissilaires" series, while No. 5 represents the highest hard bed, intercalated in the Casamayor bentonites, which are here highly gypsiferous.

No. 1. The rock is cream- and buff-colored, is quite hard and contains nodules of brown-colored iron oxide. It has a distinct gritty or ashy feel. In thin section the rock is seen to consist of a light-green-colored material. High magnification shows this material to be made up of volcanic glass fragments in a matrix of material of similar nature though not so distinctly fragmental. The glass fragments or shards are usually rectangular in shape and are similar in size and shape to those illustrated in Fig. 1A. Fragments of quartz are very common. A few fragments of feldspar (oligoclase) are present. Chalcedony appears as a cavity-filling material; it is, however, not abundant. Montmorillonite is developed on a small scale.

The rock is volcanic ash.

No. 2. This rock is similar macroscopically to No. 1. Petrographic examination reveals the presence of many rectangular and square-shaped glass fragments similar to those in Fig. 1A. These fragments are even more abundant than in rock No. 1.

No. 3. This specimen is light red in color, is soft and swells and falls apart when placed in water. It differs from Nos. 1 and 2 in that the matrix is made up of the mineral montmorillonite. High-power magnifi-

cation shows the presence of a shard structure similar to that in Nos. 1 and 2 and illustrated in Fig. 1A, but in this instance the shards are not abundant.

Fragments of quartz and oligoclase are fairly common constituents of the rock. The X-ray diffraction pattern agrees very closely with that given by montmorillonite.

The rock is bentonite.

No. 4. No. 4 is very similar both macroscopically and microscopically to No. 1.

No. 5. There is a great similarity between this specimen and No. 2. Iron oxide nodules are common in the rock. With low-power magnification the rock appears opaque in thin section; high magnification shows the opaque material to consist very largely of fragments which are very like volcanic glass and very like those shown in Fig. 1A. Oligoclase feldspar fragments are quite common constituents of the rock.

X-ray analyses of this series of rocks give further information of value. The X-ray diffraction patterns of specimens Nos. 2 and 5 agree very closely with that of No. 148. It is clear from X-ray study that these rocks, like No. 148, have been very greatly changed by the addition of material and that the rocks have been thoroughly replaced by silica in the form of opal. No. 3 gives a diffraction pattern similar to that of montmorillonite; the rock is an excellent bentonite. Rocks Nos. 1 and 4 are typical volcanic ashes in which there has been little alteration either to bentonite or to opal.

Since specimens Nos. 1–5 represent a series of rocks which are intimately associated in the field and since the series includes volcanic ashes, bentonites and rocks of the characteristic "Argiles fissilaires" type, i.e., opal-bearing rocks, it would seem that these rocks should furnish valuable information concerning the genetic relationships which exist among the rocks as a whole. The close association in the field suggests very strongly a common source of origin for the three main rock types, i.e., the volcanic ashes, the bentonites and the opal-bearing rocks. The close association of volcanic ash and bentonite is a very common feature in the mammal-bearing rocks of Patagonia.[1] The association of opal-bearing rocks with volcanic ashes and bentonites seems to be quite in order, for in every instance the opal-bearing rocks are found to be made up largely of fragments of material which are similar in size and shape to

[1]McCartney, G. C., op. cit., p. 1.

the fragments of volcanic glass found in the ash and bentonite rocks. X-ray and chemical analyses both show that the opal-bearing rocks contain a very high percentage of opal and that the original glass fragments have been replaced by opal.

At first it was considered that the great difference in shape between the shards of the Nos. 74 and 75 type—illustrated in Fig. 1B—and those of No. 148 and Nos. 1–5 type—illustrated in Fig. 1A—indicated different ash falls and that the reason for the silicification of certain horizons might be referred to ash falls of different character and composition originally. The contrast in shape of the shards does suggest different ash falls, but there is little reason to believe that any relation exists between the character of the original ash fall and the silicification of the rocks, for both types of ash rock have been thoroughly replaced by opal.

It seems to the writer that the facts presented in this paper lead to some rather important conclusions, especially in regard to an interpretation of the stratigraphic relations of the rocks in the field.

1. The so-called "Argiles fissilaires" and the volcanic ashes and bentonites are a closely related series of rocks which have a common origin, i.e., they were at one time all volcanic ashes.

2. The "Argiles fissilaires" represent certain local horizons in the early Tertiary ash and bentonite series, especially associated with the Casamayor Formation, which have been thoroughly infiltrated and replaced by opal.

3. The silicification of the "Argiles fissilaires" rocks by opal has been more or less confined to rather local areas in certain horizons in the original volcanic ash. This is thought to be due at least in part to the porous nature of the volcanic ash. Porous unaltered ash beds would be easily permeated by circulating solutions, whereas beds which were partially or entirely altered to bentonite would not be so easily permeated, for the clay-like nature of the bentonites would tend to obstruct the circulation of solutions.

4. The "Argiles fissilaires" is not considered to be a distinct formation lithologically but is rather a local member of the Tertiary sequence, or of the Casamayor, made prominent in the field because of the frequently bright color, and the presence of opal, which gives a rock highly resistant to the forces of erosion.